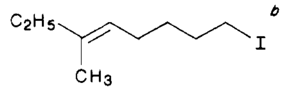
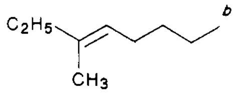
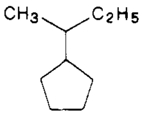
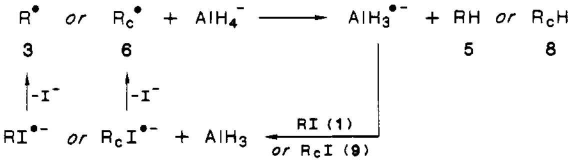
Table II. Reaction of 8-Iodo-3-methyl-3-octene (1c) (0.05 M) with LiAlH$_4$ (0.05 M)[a]

										
exp	*Z*, %	*E*, %[b]	reagent	solvent	RX time, h	*Z*, %	*E*, %		total yield,[c] %	
1	40.9	59.1	LAH	Et$_2$O	24	41.5	58.5	9.6	97.5	
2	40.5	59.5	LAD	Et$_2$O	24	40.7 (94.2% D)	59.3 (94.7% D)	18.4 (89.4% D)	97.0	n3
3	41.2	58.8	LAH	THF	3	40.9	59.1	0	98.1	
4	41.0	59.0	LAD	THF	3	40.1 (99.3% D)	59.9 (99.4% D)	0	98.1	
5	41.0	59.0	5 LAD	THF	3	40.5	59.5	0	98.1	

[a] Reductions were carried out at room temperature under laboratory light. [b] Normalized: 100% = % *Z* + % *E*. [c] Yields were determined by GLC.

Scheme II. Hydrogen Atom Radical Chain Process

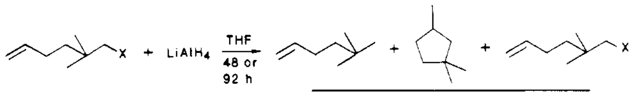


that the *Z*/*E* ratio of the product of **1c** (41/59) does not change from that of the reactant, indicating that the double bond is not affected by these groups. Importantly, when **1c** was reduced with LiAlH$_4$ in ether, cyclized product (**7c**) was formed in 9.6% yield, and when **1c** was reduced with LiAlD$_4$, cyclized product (**8c**) was formed in 18.4% yield with 89.4% deuterium incorporation.[9]

When halide **1c** (0.05 mmol) in 4 mL of dry benzene was treated with hexaphenylditin (0.005 mmol) in the presence of a sun lamp, 96.2% of starting material was recovered, and no cyclized iodide was detected after 24 h. Also the same reaction with 0.01 mmol of hexaphenylditin in 4 mL of dry ether under reflux produced 38% of the cyclized reduction product **7c**; cyclized iodide **9c** was not detected. Since cyclized iodide **9c** is not expected as an intermediate in the reaction of LiAlH$_4$ with **1c**, then the cyclized product **7c** must come from the radical **6c**. Additional convincing evidence comes from the reduction of **1c** by LiAlD$_4$ in ether. Not only is there significant protium content in the cyclized product (11%) but also in the straight chain product (5%). All of these data are clearly not compatible with Newcomb's interpretation but are compatible with the mechanism shown in Scheme I.

We would also like to report that in addition to the halogen atom radical chain process **3** → **6** $\xrightarrow{1}$ **9**, which accounts for some but not all of the cyclized products (**7**, **8**), we have found evidence to support a hydrogen atom radical chain process to account for the conversion of **3** → **5**, **6** → **8**, and **9** → **8** by reaction of radicals R$^\bullet$ (**3**) and R$_c^\bullet$ (**6**) with LiAlH$_4$ (Scheme II). Support for the hydrogen atom radical chain process is based on (1) the increased amount of **5** formed (3.3% to 9.4% to 15.2%) as the ratio of LiAlH$_4$:**1** is increased from 0.1:1 to 1:1 to 5:1, showing that radical **3** is quenched with LiAlH$_4$ at a faster rate in competition with reaction with SH, LiAlH$_4^{\bullet+}$, and the cyclization of **3** → **6**, and (2) the results of an entrainment experiment (Table III), which shows that although the chloride **11** does not react with LiAlH$_4$ in THF for 48 or 92 h, 28% reaction of chloride **11** does take place over the same period of time in the presence of an equivalent amount of iodide (**10**). It has been shown that **11** is not converted to **10** by reaction with LiI. Both of these studies are consistent with the mechanism suggested in Scheme II.

Table III. Reaction of 10 and 11 with LiAlH$_4$ in 0.5:0.5:1 Ratio

			
	% yield		
X = I (**10**)	9.4	90.1	0
X = Cl (**11**)	0	0	100
X = I + Cl (50%:50%)	8.9	52.3	36 (Cl)[a]

[a] 14% of the 50% of the chloride or 28% of the total chloride did react.

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[9] **Note added in proof.** In similar studies two additional mimics of **1b**, 4-iodo-3,3-dimethyl-1-butene and 7-iodo-2,6,6-trimethyl-2-heptene, were found to cyclize on reaction with LiAlH$_4$ to form the cyclized product in 35% and 42% yield, respectively.

A New and General Synthesis of α-Silyl Carbonyl Compounds by Si–H Insertion from Transition Metal Catalyzed Reactions of Diazo Esters and Diazo Ketones

Summary: α-Silyl esters and α-silyl ketones are formed in high yield by Rh$_2$(OAc)$_4$- or Cu(acac)$_2$-catalyzed decomposition of diazo esters and diazo ketones in the presence of organosilanes.

Sir: Although α-silyl carbonyl compounds are widely recognized for their utility in organic synthesis,[1] there are few general methods available for their preparation. The most widely investigated procedures involve enolate anion displacement of chloride from chlorosilanes.[2] However, only amide enolates undergo predominant C-silylation under ordinary conditions.[3] With ester and lactone eno-

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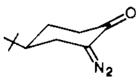
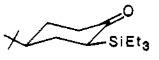
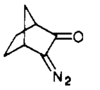
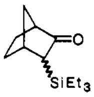
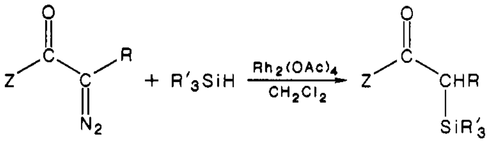
Table I. Synthesis of α-Silyl Esters and Ketones by $Rh_2(OAc)_4$-Catalyzed Decomposition of Diazo Compounds in the Presence of Organosilanes[a]

diazo compound	organosilane	$\frac{[R_3SiH]}{[ZCOC(=N_2)R]}$	product	yield,[b] %
$N_2CHCOOEt$	Et_3SiH	1.1	Et_3SiCH_2COOEt	94[c]
$N_2CHCOOEt$	Ph_3SiH	1.0	Ph_3SiCH_2COOEt	90
$N_2CHCOC(CH_3)_3$	Et_3SiH	1.5	$Et_3SiCH_2COC(CH_3)_3$	89
$N_2CHCOPh$	Et_3SiH	1.8	Et_3SiCH_2COPh	95
$N_2CHCOCH_2Ph$	Et_2SiH	2.0	$Et_3SiCH_2COCH_2Ph$	85[d]
$N_2C(CH_3)COPh$	Et_3SiH	2.0	$Et_2SiCH(CH_3)COPh$	90[e]
$N_2CHCO(CH_2)_6CH_3$	Et_3SiH	2.1	$Et_3SiCH_2CO(CH_2)_6CH_3$	89
	Et_3SiH	2.0		88[e,f]
	Et_3SiH	2.0		82[g,h]

[a] Reactions were typically performed with 2.0 mmol of diazo compound using 10 mL of dichloromethane. [b] Unless indicated otherwise, the O-silylated enol ether either was not observed or was a trace component of the reaction mixture. [c] Isolated distilled yield. [d] Contains 5% 2-indanone. [e] Includes 10% relative yield of the corresponding silyl enol ether. [f] Only one stereoisomer was obtained. [g] Includes 7% relative yield of the corresponding silyl enol ether; pure α-silyl ketone was isolated in 70% yield after distillation. [h] Formed as a 65:35 mixture of epimers.

lates, C- versus O-silylation is a function of the metal salt,[4] solvent,[2a] enolate,[5,6] and chlorosilane structure,[2a,5] but exclusive C-silylation can be made to occur for most simple esters. Ketone enolates generally form only O-silylated products,[7] although α-silyl ketones may be formed from α-bromo ketones by O-silylation, transmetalation of the resultant vinyl bromide, and subsequent rapid *O*- to *C*-silyl migration.[8] As a consequence, β-ketosilanes are often preferentially formed either by oxidation of β-hydroxysilanes[9] or by Lewis acid catalyzed rearrangement of α,β-epoxysilanes.[10] An attractive alternative to these methods, suggested by the facile intermolecular C–H insertion reactions of catalytically generated metal carbenes,[11] is carbene insertion into the Si–H bond of organosilanes. Silanes are excellent scavengers for free carbenes,[12] but their use in transition metal catalyzed reactions of diazo compounds has not been explored beyond isolated examples of copper-catalyzed reactions with ethyl diazoacetate.[13] We report the remarkable facility for Si–H insertion by metal carbenoid intermediates and describe the use of this methodology for the synthesis of α-silyl esters and ketones.

Diazo carbonyl compounds are easily accessed from carboxylic acids and ketones by a variety of standard procedures,[14] and their syntheses can generally be achieved in high yield. The success of rhodium(II) acetate for C–H insertion reactions of similarly constructed diazo compounds[15] prompted our use of this catalyst for Si–H insertion into organosilanes (eq 1). Thus, for example,



(1)

treatment of 1-diazo-2-nonanone with 2.1 molar equiv of triethylsilane in the presence of a catalytic amount of $Rh_2(OAc)_4$ resulted in the rapid evolution of dinitrogen and the production of 1-(triethylsilyl)-2-octanone in 89% yield without a trace of either the O-silylated enol ether or intramolecular C–H insertion products. Representative examples of the effectiveness of this methodology are reported in Table I. Reactions were performed at room temperature by using 1.0 mol % of $Rh_2(OAc)_4$, based on the limiting diazo compound. The diazo compound dissolved in dichloromethane was slowly added to the mixture of organosilane and $Rh_2(OAc)_4$, also in dichloromethane, through a syringe pump to minimize carbene dimer formation. After addition was complete, the resultant solution was concentrated, and the α-silyl carbonyl compound was isolated by standard procedures.

As can be seen from Table I, α-silyl esters and ketones are formed in consistently high yields by $Rh_2(OAc)_4$-catalyzed decomposition of diazo carbonyl compounds. Except in reactions of α-alkyl-substituted diazo ketones such as α-diazopropiophenone or 4-*tert*-butyl-2-diazocyclohexanone, where the silyl enol ether is a minor component of the reaction mixture,[16] O-silylation is not competitive with C-silylation. That any *O*-silyl enol ether is formed is surprising, however, in view of the presumed involvement of metal carbenes in these processes,[17] but such products may have resulted from an ene reaction of the metal carbene intermediate. As expected from a metal carbene transformation, complete retention of configuration is observed in the $Rh_2(OAc)_4$-catalyzed decomposition of ethyl diazoacetate in the presence of 1.2 molar equiv of (*S*)-(1-naphthyl)phenylmethylsilane (eq 2).[18]

$$\underset{[\alpha]_D{}^{21} = -34.5^\circ}{(S)\text{-}(1\text{-Np})PhMeSiH} + N_2CHCOOEt \xrightarrow[\substack{CH_2Cl_2 \\ 97\%}]{Rh_2(OAc)_4} \underset{[\alpha]_D{}^{20} = -4.60^\circ}{(R)\text{-}(1\text{-Np})PhMeSiCH_2COOEt} \qquad (2)$$

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(16) Increasing the bulk of the organosilane increases the relative yield of the silyl enol ether. With α-diazopropiophenone, the relative yield of O-silylated product increased from 10% (Et_3SiH) to 18% (*t*-$BuMe_2SiH$) and 20% ($MePh_2SiH$).

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Intermolecular Si–H insertion competes effectively with intramolecular processes. For example, intramolecular C–H insertion reactions[19] of 1-diazo-2-nonanone, 3-diazobicyclo[2.2.1]heptan-2-one, and 2-diazo-4-*tert*-butylcyclohexanone are not observed in the presence of organosilanes. However, electrophilic substitution from catalytic decomposition of 1-diazo-3-phenyl-2-propanone resulting in the formation of 2-indanone[20] is not completely supressed with the use of 2.0 molar equiv of triethylsilane. As an alternative, copper(II) acetylacetonate, which is not as active as $Rh_2(OAc)_4$ for electrophilic substitution reactions, promotes only C-silylation in the decomposition of 1-diazo-3-phenyl-2-propanone (91% yield with Et_3SiH, 2.5 molar equiv).

The use of $Cu(acac)_2$ as an alternative to $Rh_2(OAc)_4$ was examined. With α-diazoacetophenone, $Cu(acac)_2$ promoted Si–H insertion with triethylsilane to give the corresponding α-(triethylsilyl)acetophenone cleanly in 95% yield when this reaction was performed in refluxing dichloromethane.[21] However, the product mixture from the reaction between α-diazopropiophenone and triethylsilane was complex relative to that from reactions performed with $Rh_2(OAc)_4$, the yield of silylated ketone was low (<60%), and the relative amount of O-silylation (12%) was comparable to that obtained with $Rh_2(OAc)_4$. Thus $Cu(acac)_2$ in refluxing dichloromethane appears to be comparable to $Rh_2(OAc)_4$ in its effectiveness for Si–H insertion except with α-alkyl-substituted diazo ketones. Investigations of this and related insertion reactions are currently under way.

Acknowledgment. Support for this research from the National Science Foundation and Robert G. Welch Foundation is gratefully acknowledged. The National Science Foundation and Keck Foundation provided partial funding for the high-field NMR spectrometer employed for these investigations. We thank the Johnson Matthey Co. for their loan of rhodium(III) chloride and Peter J. Stang for providing us with a generous sample of optically pure (*S*)-(1-naphthyl)phenylmethylsilane.

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[21] In contrast, $Cu(OTf)_2$ gave complex mixture of products even when this reaction was performed at 0 °C.

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Received August 9, 1988

A Concise Route to the Penitrem Series of Tremorgenic Mycotoxins: Preparation of an Oxocane-Fused Indole

Summary: In this paper we record an efficient synthesis of tricyclic aniline **4**, an advanced intermediate which embodies the B–C–D rings of penitrem D (**1**). In addition, a diminutive version of the natural product, hexacycle **10**, was prepared.

Sir: In an elegant series of papers published in 1981–1983, Steyn et al. announced the structures of the penitrems (A–F), a small family of tremorgenic mycotoxins produced by the ergot fungus *Penicillium crustosum*.[1,2] The connectivity and relative stereochemistry of these complex metabolites were deduced primarily by means of high-field NMR experiments; the "partial resolution" method of Horeau served to establish their absolute configuration.[3] At that time, several studies had already implicated the penitrems in livestock syndromes characterized by acute neurologic dysfunction.[2a,4] Intrigued by their novel architecture, we recently mounted an investigation with a

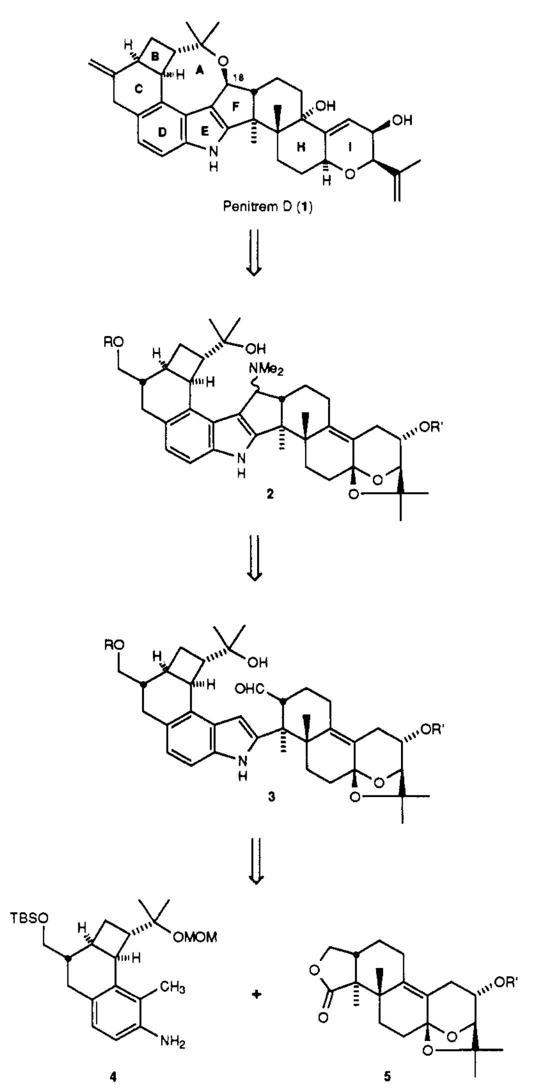

Figure 1.

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